ROSAT OBSERVATIONS OF THE X-RAY BINARY HD 154791

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Final Report

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Deep Imaging in the Taurus-Auriga Molecular Cloud

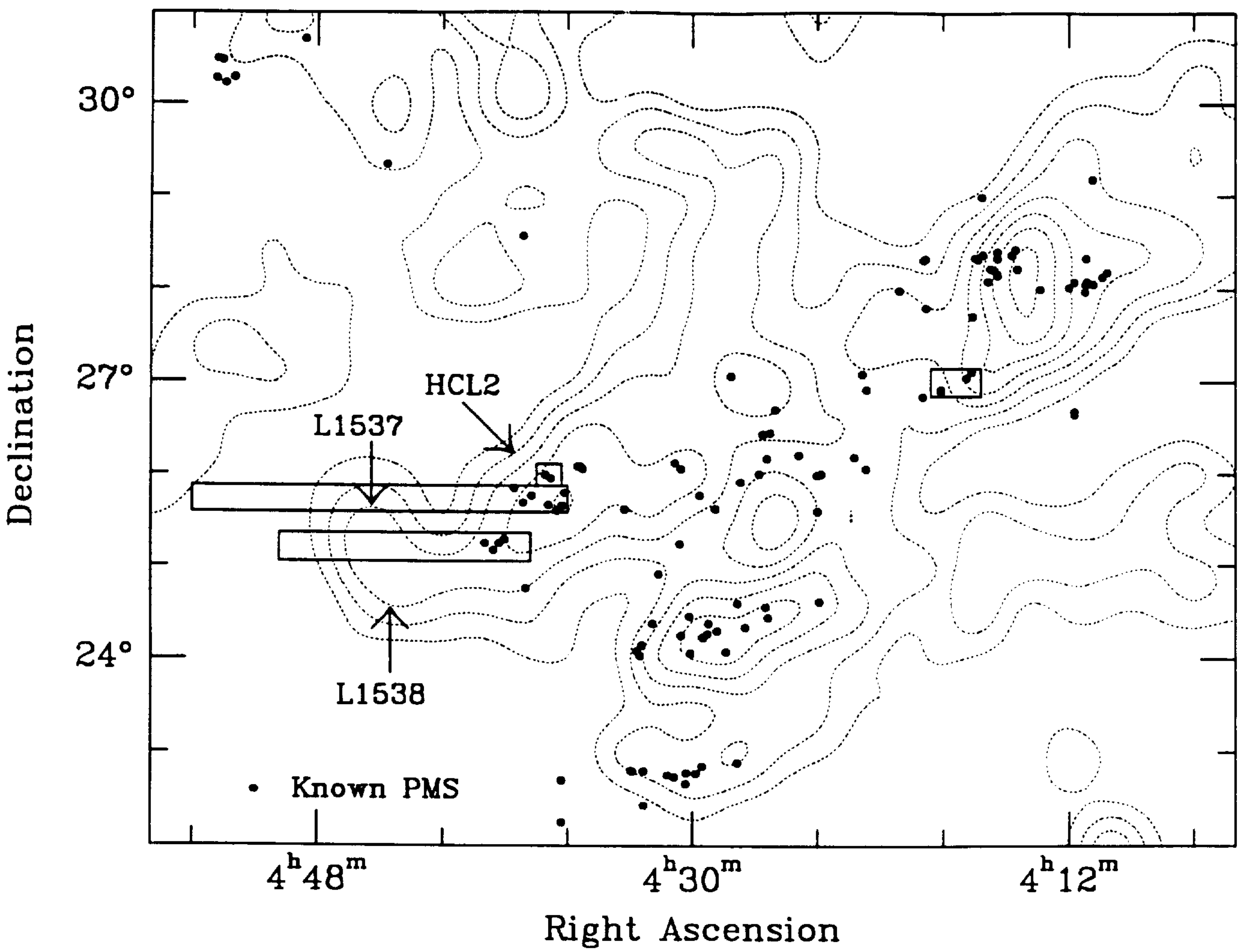
The Taurus-Auriga molecular cloud is one of the nearest and best studied regions of star formation. Taurus is more tenuous and less massive than the giant molecular clouds believed to be the birthplaces of most stars and is not as active a stellar nursery as Orion or Ophiuchus. Nevertheless, there are several advantages to studying star formation in Taurus-Auriga. Besides its proximity, the relatively low dust obscuration through the cloud allows us to detect many of its young stars with optical observations. These data are particularly important, because young stars cannot be assigned masses, and hence ages, without optical spectral types. Its northerly declination has also resulted in both a longer historical record and more complete coverage than for otherwise similar southern star forming regions.

We have been surveying the Taurus dark cloud for young stars using a variety of techniques. Two optical proper motion surveys identified 8 new pre-main sequence stars; an IRAS-based program discovered 6 new embedded sources and 4–6 new T Tauri stars. Finally, an optical objective prism survey found 12 new T Tauri stars. Our goal in this project is to examine and compare star formation in the dark clouds Heiles cloud 2 (HCL2), L1537, L1538, and L1544. HCL2 is a very dense region actively forming young stars and contains 5–6 very young, deeply embedded sources; both L1537 and L1538 have no known pre-main sequence stars; L1544 contains 7 optically visible T Tauri stars. These clouds appear roughly similar on optical sky survey plates. We would like to know why some of the clouds are active and why some are not. The first goal of the project is to survey the regions using IR photometry to identify very red pre-main sequence stars and X-ray imaging to identify solar-type young stars missed in the near-IR survey. We will follow up these observations with molecular line surveys to compare the conditions in various clouds with their star formation efficiencies.

This project has had an unusual history. Our first X-ray proposal was submitted in 1991 and given priority 3 status. No observations were acquired during this year. Our second proposal was given priority 1 status for 1992, but the first proposal was funded! However, we did not receive the correct amount of money; this money was later given to this grant (which is really for an X-ray binary not star formation). The ROSAT team acquired data for our targets in late 1992, but we did not get the data tapes until March-June 1993. The data look very nice, but we received them too late to identify candidate pre-main sequence stars and apply for the necessary ground-based spectroscopic time to confirm them in Fall 1993 when Taurus is best observed from Arizona. Our plan is to identify a set of candidates this spring in time to apply for Fall 1994 time. In spite of these delays, we have identified several embedded protostars – including the very young object IRAS04368+2557 – as faint X-ray sources. These are the first Taurus embedded source to be detected in X-rays; Montmerle has reported several X-ray sources among the class I sources in the Ophiuchus dark cloud.

The near-IR portion of this program is complete. We used the KPNO SQIID to image roughly 2 square degrees of the Taurus cloud (Figure 1). This survey concentrated on HCL2, L1537, and L1538. We identified $\sim$ 60 candidate young stars from near-IR colors and acquired optical spectra for all stars brighter than V $\sim$ 16–17. Only two of these objects turns out to be a pre-main sequence star. Both of these candidates can be associated with a faint IRAS source. One of these sources was identified in several previous surveys; our results thus confirm it as a pre-main sequence star. We found *no* pre-main sequence objects in L1537 and L1538. Thus, neither of these clouds has formed any pre-main sequence stars. Our results show that the mean extinction through HCL is $\sim$ 4 mag at V; we estimate $A_V \lesssim 1.5$ mag for the L1537 and L1538 dark clouds. Herbig has previously suggested a minimum optical extinction, $A_V \sim 1.5$ mag, necessary to trigger star formation. Our survey confirms this conclusion.

Figure 1 – The position of our near-IR survey areas projected against contours of ^{12}CO column density (Ungerechts & Thaddeus 1987). Large arrows indicate approximate positions of the dark clouds L1537, L1538 and HCL2 relative to the ^{12}CO contours. Filled circles indicate the positions of all known young stars in this region.



The M0 star HD 154791 is one of two binary systems composed of a hard X-ray source (presumably an accreting neutron star) and an evolved red giant. The higher excitation system GX1+4 (V2116 Oph) consists of a more evolved giant and a more luminous X-ray source but has a very large extinction ($A_V \sim$ 8–10 mag) that makes it hard to study in detail. The galactic reddening towards HD 154791 is much smaller, $A_V \sim 1$ mag, and therefore is a simpler system to analyze.

We acquired contemporaneous IUE and ROSAT observations of HD 154791 on 23-25 March 1992. The system was detected with both instruments: IUE recorded a weak SWP continuum and emission from C III] and C IV, while the ROST PSPC detector found a modest X-ray source near the position of HD 154791.

Our goal in this project is to determine the source of the UV and X-ray emission. This may turn out to be difficult, because the source has varied considerably over the last ten years. Each of the three IUE observations shows very different continuum and emission line intensities, and the X-ray flux has varied by a factor of at least 10 since 1980. To determine if these variations can be produced by orbital motion (or are intrinsic to the accreting source), we decided to begin our study with an analysis of optical radial velocity data of the M giant. These data show small variations with an apparent period of 1200 days. Our data from Mt. Hopkins indicate a semi-amplitude of 2.2 ± 0.6 km s^{-1} for P = 1216 days. The phasing of the orbit suggests that some of the apparent variability in this object may be caused by eclipses of the accreting source rather than actual changes in luminosity. However, the time of spectroscopic conjunction is not well-constrained by our current dataset. Fortunately, Dr. V. Smith (U. Texas) has about one dozen velocity measurements at times that fill a large gap in our own dataset. These data – together with data from the last year that are currently being analyzed – should allow us to derive a better period and time of spectroscopic conjunction. We can then begin our analysis of the UV and X-ray data.

Our current plan to finish this project is as follows. We should be able to complete the analysis of the spectroscopic dataset and derive a good orbital period this spring. We will then phase the X-ray and UV data this summer and anticipate writing a short paper on this system this fall.

Publications

"A Near-Infrared Survey for Pre-Main Sequence Stars in the Taurus-Auriga Molecular Cloud," M. Gomez, S. J. Kenyon, & L. Hartmann, AJ, in press